A procedure for testing the function of a lamp circuit

The invention relates to a procedure for testing the function of a lamp circuit, consisting of at least one lamp, by measuring the current and voltage.

The nominal power of a lamp is the electrical power input of the lamp when defined standard conditions are present, in particular the application of a nominal voltage; it is given by lamp manufacturers as a lamp parameter alongside the nominal voltage, and is required by manufacturers of lighting systems as a standard value to be maintained. However, some lamps deviate significantly from the given standard values, which may lead to faults or defects in the lighting control or the lamps.

Lighting systems are also used in safety-related applications, in particular in motor vehicles. With safety-critical applications of this type, it is necessary to check during operation for defects, or for non standard-compliant lamps which may have been installed.

For example, when filament lamps are triggered in the motor vehicle, the switch output can already be diagnosed by the electronic system, for example, and information can be provided regarding the state of the load. By recognising the operating states and/or the measurement of the determining electrical values, the failure of the lamp can be detected, and a message can be sent to the driver or to a diagnosis system.

The precision of the diagnosis procedure is restricted by different parameters, such as the precision of the measurements, for example, and above all by the electrical model of the lamps used.

The simplest procedure for determining the lamp state is a digital determination of the output voltage when in a switched-off state. When the lamp is defective, the circuit is interrupted, which can be detected on the voltage level.

Improved procedures use a current measurement when the lamp is in a switched-on state, with a measuring resistor or current mirror switches or integrated solutions

such as the so-called "SenseFETs" with a control input and a current signal output, as illustrated in Fig. 1.

However, the voltage on the lamp circuit cannot be adopted accordingly as a constant value of the nominal voltage in a wide range of applications, in particular in motor vehicles. However, if the voltage deviates from the nominal voltage, the current power input produced from the voltage and current does not correspond to the nominal power.

In addition, the current lamp resistance may fluctuate due to:

- the use of different lamp types
- the different nominal voltage of the different lamp types
- deviations from different manufacturers
- scattering within a lamp type
- lamp ageing

Particularly problematic is the diagnosis with two or more lamps which are switched in parallel, which can only be detected, if at all, when the electronic system is calibrated.

In addition, the use of intact lamps which deviate from the specification, however, or a fault in individual lamps, can lead to faults on the control unit or other lamps which are switched in parallel with the lamp.

A procedure for testing the function of a lamp circuit consisting of at least one lamp is known from US-A-5 578 998. The function test is conducted by measuring the current and the voltage on a resistance.

A further procedure for testing the function of a lamp is known from EP-A-0 507. In order to test the function, the current and the voltage are measured on a resistance.

The object of the invention is to provide a procedure for testing the function of a lamp circuit which also enables a function test with a high level of precision even when the operating voltage deviates from the nominal voltage. This object is attained by the

features described in patent claim 1. Advantageous further embodiments are described in the subordinate claims.

The lamp circuit consists of at least one lamp, i.e. the procedure is also suitable in particular for a lamp circuit with several lamps switched in parallel. By measuring the current and voltage, the effective operating state is recorded. Each function test is based on a comparison of measured values with set values.

Here, a polynomial of at least the 1^{st} order, according to $R=c*U+d$, is taken into account for the resistance value, depending on the voltage effectively measured on the lamp circuit. Finally, it is not of decisive importance here whether the polynomial is taken into account in relation to the set values, or when the measured values are converted into derived values, i.e. whether the measured values are standardised according to constant set values or the set values are adapted to the operating conditions.

The resistance value of the lamp can be determined as a polynomial of at least the 1^{st} order, or can be derived from a further value, as will be explained in detail below.

The parameters of the polynomial are determined by a quantity of measurements which at least correspond to the order of the polynomial when operating conditions are known to be different.

The higher the order of the polynomial, the more precisely the set values can be predicted, or the measured values can be approximated to a fixed set value.

Preferably, the resistance value is related to the nominal power, in which the parameters of the polynomial of the resistance value are in each case multiplied with the nominal power when operating conditions are known. In this way, when different lamps are used, a lower degree of fluctuation and improved value specification can be achieved.

If the lamps show nominal voltages which deviate from each other under the nominal power, the parameters of the polynomial are standardised to a shared nominal

voltage, in which, when measurements are taken when the operating conditions are known, the parameters of the polynomial of the resistance value are in each case multiplied by the ratio from the shared nominal voltage to the determined voltage of the lamps under nominal voltage. In this way, when different lamps are used, an even lower degree of fluctuation and a better value specification can be achieved.

Preferably, the nominal power of the lamp circuit can be determined as the value to be compared with a specified value which is determined from the current and voltage, and the parameters of the polynomial of the resistance value which are determined from the reference measurements in order to determine the calculable nominal power for the lamp currently installed, and which are compared with the set value.

Alternatively, the set current through the lamp circuit under the effective voltage can be determined as a specified value, i.e. from the voltage, the parameters are first used to calculate the resistance value for the effective voltage, which is then used to determine the anticipated set current, and compared with the actual current.

Here, each of the standardisations for nominal power and nominal voltage are naturally taken into account in each case.

As a result, a lighting system consisting of at least one lamp and one control unit is possible, which records the current and voltage, and which in accordance with the procedure in one of the claims below, calculates the resistance of the lamp or a value which is derived from it, compares it with the specified values and detects any deviation which may occur from the specified values which indicates that the lamp is defective or does not comply with the specification.

Thanks to the improved approximation, two or more lamps which are switched in parallel can be monitored together, and it can be detected whether one of the lamps is defective or does not comply with the specification. Preferably, with lamps of a different nominal power or resistance, a conclusion is reached from the scale of the deviation from the specified values as to which of the lamps which are switched in parallel is defective.

The invention shall now be explained below in greater detail by way of exemplary embodiments which are explained with reference to the drawings, in which:

Fig. 1 shows a preferred switch arrangement with SenseFet for measuring the current in the lamp circuit

Fig. 2 shows a sketch of the achievable improvement in the description of the lamp resistance when a polynomial of the first order is used

Fig. 3 shows a sketch of the actual lamp resistance procedure for different lamps

Fig. 4 shows the degree of fluctuation when a polynomial of the third order is used

Fig. 5 shows the degree of fluctuation with different lamp types and standardisation to the nominal power

Fig. 6 shows the degree of fluctuation with different lamp types and standardisation to the nominal power and a shared average nominal voltage

Fig. 7 shows the relative deviation with different lamp types and standardisation to the nominal power and a shared average nominal voltage

Fig. 8 shows the parallel switching of several lamps

The present invention therefore describes a procedure for testing the function of a lamp circuit, in particular for the precise determination of the nominal lamp power from the measured lamp current under operating voltage, using an empirically determined lamp model.

Here, measurements are first taken in measuring rows with operating conditions of the working current of the lamp which are known to differ from each other, depending on the operating voltage and for one lamp type in each case, and these measurements are then used to calculate the parameters for the polynomial of the resistor.

The quantity of measurements already corresponds at least to the order of the polynomial in order to ensure the unambiguousness of the calculation of the

parameters, although in practise, it is significantly larger in order to offset the measurement fluctuations. The parameters are then accordingly well approximated, but can be adopted as a constant, however, for the subsequent measurements when the operating voltage deviates from the nominal voltage.

In this way, with a current measured voltage which is derived from these constant parameters, the resistance can be determined far more precisely, and therefore a more exact value can be given for the nominal power.

The lamp resistance over the applied voltage is a polynomial of a high order and is shown in principle in Fig. 3. For a diagnosis, it is sufficient to observe the resistance of the lamp in the working voltage range ($U_{min}...U_{max}$). In this range, the resistance can be roughly approximated with a polynomial of the 1^{st} order, and can be approximated to a high degree of accuracy with a polynomial of the 3^{rd} order. Here, Fig. 2 makes clear that based on a nominal resistance under a nominal voltage and under a defined degree of fluctuation (thick lines around the broken central line), a fixed specification of threshold values R_{max} and R_{min} or an approach using the resistance value as a constant lead to statements which are so ambiguous that neither the installation of a lamp which deviates from the specification, nor a defect in a lamp with several lamps which are switched in parallel, can be detected.

This results in significant differences for all known variables (different lamp types and manufacturers, parameter scattering, ageing), which make a determination of the lamp power, in particular when different lamp types are switched in parallel, more imprecise, as can be seen from the degree of fluctuation shown in Fig. 3, whereby the broken line shows the average procedure, and the unbroken lines show the limits of the actual characteristic curves of the lamp.

A decisive step forward which shows an improvement over this method can be achieved by standardising the resistance (or the parameters) to the nominal power, and even better, to the nominal voltage.

Here, the polynomial of the voltage-dependant lamp resistance is multiplied by the nominal power of the lamp:

$$R_{spec} = \frac{U_{lamp}}{I_{lamp}} \cdot P_{nom} \quad [\Omega \cdot W]; \qquad \text{(eq. 1)}$$

It is then standardised to the shared nominal voltage, in order to offset the different nominal voltages for the different lamp types.

$$R_{spec\_norm} = R_{spec} \cdot \frac{U_{norm}}{U_{nom\_act}} = \frac{U_{lamp}}{I_{lamp}} \cdot P_{nom} \cdot \frac{U_{norm}}{U_{nom\_act}} \quad [\Omega \cdot W]; \qquad \text{(eq. 2)}$$

whereby U_{norm} is the nominal voltage of the lamp, e.g. 12.0V

and U_{nom_act} is the averaged voltage under the nominal voltage of a lamp type.

These standardisations result in an almost identical polynomial R_{spec_stand} for all lamp types, in which only a narrow tolerance band now needs to be considered, as illustrated in Fig. 4.

By converting eq. 3, the precise nominal power of the lamp can be calculated from the polynomial, dependant on the operating voltage, or interpolated from a table:

$$P_{nom} = R_{spec\_norm} \cdot \frac{I_{lamp} \cdot U_{nom\_act}}{U_{lamp} \cdot U_{norm}}; \qquad \text{(eq. 3)}$$

with $R_{spec\_norm} = a \cdot U^3 + b \cdot U^2 + c \cdot U + d \quad [\Omega \cdot W];$

The polynomial is determined using measuring rows, whereby the calculation of the specific standardised resistance is less prone to error, the fewer different lamp types are included in order to determine the polynomial.

Here, the level of error in the interpolation curves of R_{spec_stand} in relation to each other is lower than the component scattering with a lamp type.

Fig. 5 now shows the degree of fluctuation following standardisation to the nominal power with real characteristic curves for approx. 15 lamps commonly used in the motor vehicle industry with a completely different nominal power (5-60 Watts). It can already be very clearly surmised from a visual inspection that lamps with a completely different nominal power, and therefore with a different inner resistance, can be standardised to a relatively high degree of precision.

The table below explains this principle in greater detail for certain selected lamp types. All lamps are motor vehicle lamps for 12-volt on-board networks.

Lamp type	**1**	**2**	**3**	**4**	**5**	**Ø with nominal voltage**	**Absolute scatt.**	**Relative scatt.**
Nominal power [W]	60	55	60	7	21			
Nominal voltage [V]	12.25	12.6	11.85	12.8	11.75			
Nominal current [A]	4.9	4.37	5.06	0.55	1.79			
Rnom=U/I	2.50	2.88	2.34	23.27	6.56			
Rspec=R*Pnom	150.00	158.58	140.51	162.91	137.85	**149.97**	10.93	7.29
d [Ohm] =	37	39.79	37.93	42.5	36.1	**38.66**	2.54	6.58
c [Ohm / V] =	13.86	14.73	13.29	13.9	13.5	**13.86**	0.55	3.97
b [Ohm / V^2] =	-0.5068	-0.558	-0.4926	-0.5	- 0.5075	**-0.51**	0.03	5.04
a [Ohm / V^3] =	0.009	0.0103	0.0087	0.0095	0.0097	**0.01**	0.00	6.60

Here, the nominal voltage and the nominal current are the values which occur when the nominal power is present.

While the nominal resistances differ significantly among lamps with different powers (approx. 23 Ohm with a 7-Watt lamp as opposed to 2.5 Ohm with a 60-Watt lamp), the specific resistance value which is standardised to the nominal power is highly constant, with an average value of 150 and a percentage standard deviation of approx. 7%. In other words, lamps with a different nominal power can be characterised with a relatively high degree of precision using a specific reference value or corresponding parameter, a,b,c,d of the polynomial.

It can also be clearly seen in the examples in the above table that the lamps partly show voltage values when under the nominal power which already clearly deviate from the specified on-board network voltage of 12 volts. It can also be seen that the two 60-Watt lamp types also still show nominal resistance values which deviate from each other.

For this reason, a further standardisation is extended to a shared average nominal voltage, here of 12 volts.

Fig. 6 shows the degree of fluctuation with different lamp types, which has again been significantly reduced as opposed to Fig. 5, and Fig. 7 shows the relative deviation with different lamp types and the standardisation to the nominal power and a shared average nominal voltage.

It has been assumed in the above description that the feed wires and their electric resistance have been negligible as opposed to the lamp resistance. However, precisely in motor vehicles, feed wires of up to 6 meters in length, and yet which have narrow diameters are sometimes laid, which leads to wire resistances of up to > 200 Milliohms. If further wire resistances caused by corrosion and incomplete contact transitions now arise, then they can total up to 1 Ohm, and the losses occurring are not always negligible against lamp resistances of 3-30 Ohm.

For this reason, the opportunity is also provided to record and to take into account this resistance value in the wire.

For example, when the resistance of the spiral-wound filament(s) significantly alters due to age, this can be detected by taking measurements under different operating voltages.

Since the measurement of the operating voltage on the lamp by the electronic system would be very costly, the voltage can be more simply calculated by estimating the resistances in the load circuit. For this purpose, the operating voltage is measured on the control device input, and the voltage on the lamp is approximately calculated from the current and the resistances:

$$U_{lamp} = U_{batt} - I_{lamp} \cdot (R_{DSon} + R_{feed}) \quad ; \qquad \text{(eq. 4)}$$

whereby R_{DSon}= the switch-on resistance of the power switch

R_{feed}= the resistance of the lamp feed, including the transition resistance on the lamp socket.

The precision of the calculation of the lamp power can however also be further increased without directly measuring the wire, when different operating voltage measurements are utilised in order to determine the nominal lamp power.

This is based on the fact that when the calculation is made according to eq. 3, the nominal power of the lamp must be constant. If a lamp circuit therefore shows deviating nominal voltages with two measurements made in succession with different voltages, without the lamp having been replaced, this can be used to deduce the influence of the feed wire.

Accordingly, a cyclical recording of the measured nominal power and the operating voltage can be made for a subsequent error analysis, whereby the recorded values are stored, at least when significant deviations occur from the specified values, thus providing several measurements under different operating conditions, which are available for verifying and deducing the error location or error type. In addition, a time reference, for example using a system counter, is also stored, so that when changes are made, this can be clearly assigned within correspondingly short time periods.

By calibrating the electronic system with a precisely defined load, the error of the current measurement circuit can be further reduced, thus further improving precision.

The procedure described above therefore makes it possible to calculate the nominal load connected to the switch output to a high degree of precision.

A further advantage of the invention lies in the comprehensive diagnosis options when two or more lamps are connected to a switch output, where at least the failure of one lamp, and preferably also the installation of lamps which do not comply with the specification is detected. This enables:

- savings in costs and space requirements through the reduction in the number of outputs or switches, i.e. several lamps are controlled with one output
- a reduction in the range of different variants (e.g. different rear light/brake light concept for the USA version, the connection of a sidemarker in the USA version, and the parallel switching of indicator lights)
- the detection of a potential overload due to the impermissible parallel switching of additional lamps

The following table shows the different diagnosis options for different configurations:

Configuration	Diagnosis

	Connected nominal power	Lamp type	Failure of one lamp	Failure of two lamps	Wire data and condition
1 lamp	yes	2 measurements	yes	-	X
2 lamps with same type	yes	2 measurements	yes	yes	X
2 lamps with different type	X	X)	yes	yes	X
3 lamps with same type	yes	2 measurements	yes	yes	X
3 lamps with different type	X	X	yes	yes	X
N >3 lamps with same type	yes	X	yes (for N ≤ 4)	yes (for N ≤ 6)	X

X – plausibility from 2 measurements with different nominal voltage possible, in order to eliminate feed influences.

The error detection options with parallel switched lamps will be explained using the example of an indicator light control according to Fig. 8, consisting of two 20-Watt lamps with the same construction at the front and rear of the motor vehicle, and an additional side light with 5 Watts, controlled via a shared switch. The table shows the resulting values with a nominal voltage of 12 volts.

L1	L2	L3	Total
20W	20W	5W	45W
1.67 A	1.67 A	0.42 A	3.75 A
7.2 Ω	7.2 Ω	28.8 Ω	3.2 Ohm

It can immediately be seen that with the very rough threshold definition to offset temperature and voltage fluctuations which has been commonly made to date, it has never been possible to detect a failure of the smaller 5-Watt lamp, while even the failure or installation of a deviant 20-Watt lamp could hardly be detected, if a required tolerance of 50% $\pm$ 3 Ohm is taken into account.

Thanks to the significantly more precise determination, cases when

L3 defective – nominal power still only approx. 40 Watts

L1 or L2 defective – nominal power still approx. 25 Watts

L3 and L1 or L2 defective – nominal power still approx. 20 Watts, can be differentiated from each other.

Since the nominal power can be given with a model-dependant tolerance of approx. 10%, the deviations can now be detected based on faults on the line.

The procedure can in addition be used both with continuous triggering and when the lamp is operated in clocking mode. With clocking mode, i.e. in particular with PWM triggering of the lamps, the nominal voltage on the lamp is preferably the same as the effective value of the output signal

$$U_{lamp} \approx U_{batt} \cdot \sqrt{dc.} \quad ; \qquad \text{(eq. 5)}$$

with a dc. = (duty cycle) = switch-on multicycle control factor of the pulse width modulation, i.e. the quadratic correlation of the effective value is preferably taken into account, instead of a linear calculation $U_{lamp} \approx U_{batt} * T_{on}/T_{total}$.

It should be stated again that by altering the ohmic laws, this resistance model for lamps can also be used in the same way directly for the specification of current values which are dependant on the effective voltage, and the comparison with the current measured in each case is then made. An alternative would also be a

comparison of the effective voltage with a set voltage calculated from the effective current and resistance model, whereby the resistance value itself is in turn dependant on the effective voltage.